| AD NUMBER |
|---|
| **AD821593** |
| LIMITATION CHANGES |
| TO: **Approved for public release; distribution is unlimited.** |
| FROM: **Distribution authorized to U.S. Gov't. agencies and their contractors; Critical Technology; 15 SEP 1967. Other requests shall be referred to Air Force Office of Scientific Research, Attn: Bolling AFB, Washington, DC. This document contains export-controlled technical data.** |
| AUTHORITY |
| **AFOSR ltr dtd 12 Nov 1971** |

Service through Science



Quarterly Technical Summary Report No. 7

June 1, 1967 to August 31, 1967

# RESEARCH ON THE DEFLAGRATION OF HIGH-ENERGY SOLID OXIDIZERS

Contract No. AF 49(638)-1645

To

Air Force Office of Scientific Research
Washington, D. C.

September 15, 1967

ATLANTIC RESEARCH

ATLANTIC RESEARCH CORPORATION
ALEXANDRIA, VIRGINIA

Quarterly Technical Summary Report No. 7
June 1, 1967 to August 31, 1967

# RESEARCH ON THE DEFLAGRATION OF HIGH-ENERGY SOLID OXIDIZERS

Contract No. AF 49(638)-1645

To:

Air Force Office of Scientific Research
Washington, D.C.

Contributors: G. von Elbe, Chief Investigator
E. T. McHale

Consultants: R. Friedman
J. B. Levy

Kinetics and Combustion Group
Atlantic Research Corporation
Alexandria, Virginia

September 15, 1967

# TABLE OF CONTENTS

## I. ABSTRACT AND INTRODUCTION

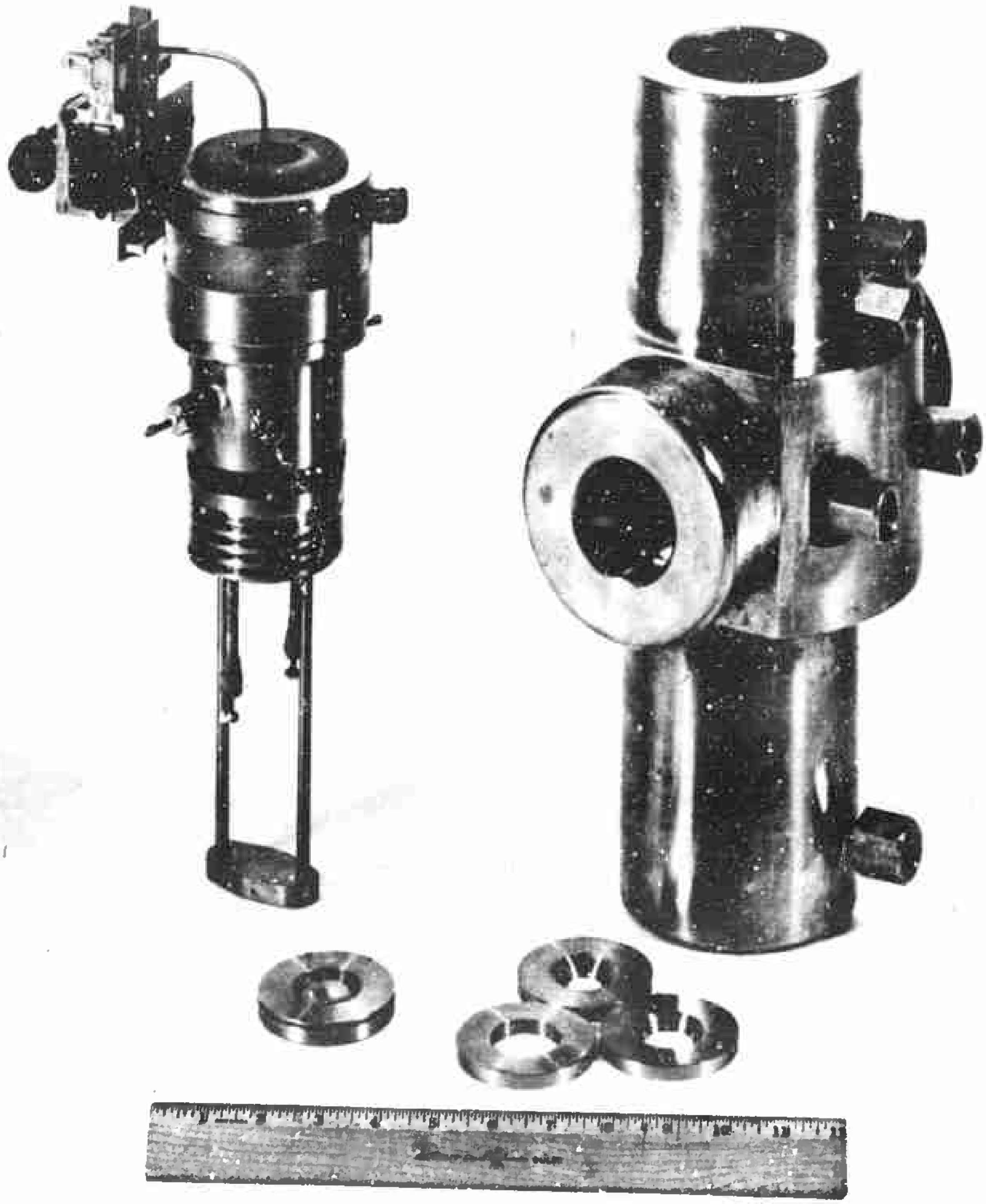
A new phase of the program, the study of solid propellant and oxidizer extinguishment by rapid depressurization, began during this quarter. In this report we describe the apparatus used for this work and the results obtained on the first propellant tested.

The apparatus is an optical strand burner modified to allow rapid depressurization by venting. At pressures of 2000 psi, pressure decay rates of $5 \times 10^5$ psi/sec can be achieved. Experiments were carried out on a polyvinylchloride-ammonium perchlorate composite propellant, over a range of initial pressures of 68 to 430 psia with decay rates as high as $10^5$ psi/sec. The experimental extinguishment results are compared with theory.

## II. DESCRIPTION OF APPARATUS FOR EXTINGUISHMENT

An optical strand burner was modified for use as a laboratory-scale apparatus to study extinguishment by rapid depressurization. The advantages of this type of apparatus are that studies can be conveniently carried out on small strand-size samples of propellant and high-speed motion pictures can be taken of the extinguishment event. A photograph of the disassembled equipment is shown in Figure 1. On the right is the bomb body which has an internal volume of about 300cc and contains inlet and outlet connections for gas pressurizing and purging. Fused silica windows are provided for taking motion pictures and for monitoring the propellant flame luminosity with a phototube. A #6365 Dumont Multiplier Phototube is used which has an S-11 spectral response. Also mounted in the body in a plane with the propellant surface is a Kistler pressure transducer.

On the left of the photo is shown the bomb head which has a 1-1/4" hole drilled straight through the top. This vent is sealed with a stainless steel frangible diaphragm which, together with an orifice plate to control the depressurization rate, is inserted under the screw cap on top. A diaphragm in a set of retaining rings and three orifice inserts are shown at the bottom of the photo. The head also contains ignition leads and posts to support the



15565

Figure 1. Photograph of Modified Optical Bomb for Study of Extinguishment of Solid-Propellant Strands by Rapid Depressurization. (Discussed in text.)

stage on which strands are mounted. Attached to the top of the head is a solenoid-driven plunger for rupturing the diaphragm.

A run is carried out by pressurizing the bomb and igniting a strand (leached to prevent side burning). After steady combustion is attained, the electrically-timed puncture of the diaphragm is effected and simultaneously a dual-trace oscilloscope is triggered. The outputs of the phototube and pressure transducer are fed into the scope which records the luminosity and pressure decay with time. A Polaroid photo of a typical oscilloscope display is shown in Figure 2.

The oscilloscope display photos are analyzed by measuring tangents to the pressure-time curve at a number of points along the line using an optically flat piece of half-silvered glass. The instantaneous (-dP/dt)-values are then computed and from a plot of these versus pressure the critical extinction (-dP/dt - P)-point (luminosity zero) is determined. The apparatus can be used at pressures as high as at least 2000 psi with corresponding pressure decay rates of $5 \times 10^5$ psi/sec. At present there are only provisions for venting to ambient pressure.

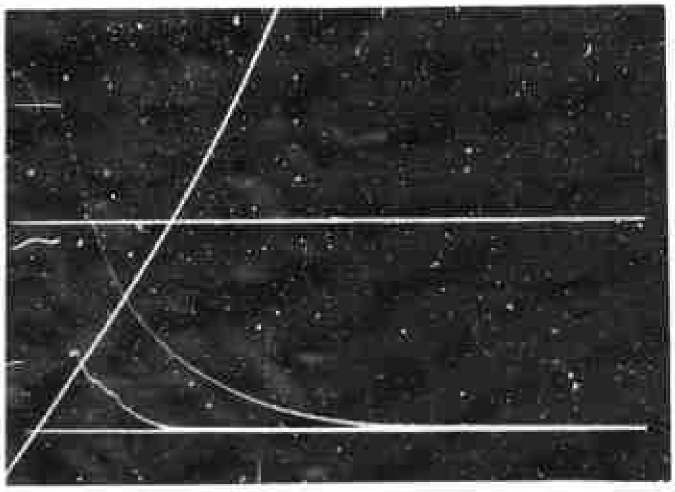
## III. INITIAL RESULTS AND COMPARISON TO THEORY

An extinguishment study was made on one candidate propellant of the Arcite series. This was a non-aluminized, polyvinylchloride-based composite containing 10 percent dioctyl adipate plasticizer and approximately 80 percent bimodal ammonium perchlorate. There was a trace of carbon black but no burning rate catalyst. Burning rates were measured over the pressure range of the extinguishment study and are given by the equation:

$$r_o = b\, P^n = .0128\, P^{.567} \quad , \qquad (1)$$

where $r_o$ is the steady-state burning rate in in/sec when P is in psia.

Fourteen runs were made at initial pressures varying from 67.5 to 430 psia. Ten extinguishments were obtained and in four runs the depressurization



15564

Figure 2. Polaroid Photo of Typical Oscilloscope Display (Run No. 14). Upper Trace is Pressure Decay from Initial Pressure of 129 psia. Lower Trace is Propellant Flame Luminosity Measured with Phototube. Horizontal Lines are Pressure Calibrations of 15 and 73 psig. Sweep Time is 5 msec/division.

rate was too low to cause extinction. A summary of pertinent data is given in Table I. In this table, $P_i$ is the initial pressure; $P_e$ is the pressure at which extinction occurred which was read directly off the oscilloscope records; $-dP/dt$ is the rate of pressure decay at $P_e$, the instant of extinction; the other quantities are discussed below.

The results must be discussed in relation to theoretical concepts of propellant combustion and extinguishment. Several theories of extinguishment have been presented (1-6), and in this report we shall not review these theories, but only note that there is substantial agreement among those (1,5,6) that yield dimensional transient burning rate expressions. The discussion is limited to a comparison of the experimental results with the predictions of theory 6.

According to reference 6, the linear ablation rate of a solid propellant grain during a pressure transient (decrease) is given by

$$r = b P^n \left( 1 + \frac{2\alpha n}{b^2} P^{-(2n+1)} \frac{dP}{dt} \right) \qquad (2)$$

where $\alpha = \lambda/\rho C_p$ is the thermal diffusivity of the solid and $b P^n = r_o$ is the steady-state burning rate. Extinction occurs when $r = 0$, so that

$$-\frac{dP}{dt} = \frac{(b P^n)^2}{2\alpha n} P = \frac{r_o^2}{2\alpha n} P \qquad (3)$$

A log-log plot of dP/dt vs. P will yield a straight line which defines the theoretical extinction boundary. Equation (3) is plotted in Figure 3 using the measured steady-state burning rates for the propellant of this study and taking $\alpha = .00020$ $in^2$/sec, which is the approximate average thermal diffusivity for this Arcite. The points are the experimental data of Table I for the ten runs in which the burning was quenched. The dashed line shows the experimental (dP/dt - P)-curve for one typical run (#14). Of the four runs in which extinction did not occur only one (#7) crossed the theoretical boundary line, the others all lying in the non-extinction region of the graph. In run #9 extinction occurred, but after the oscilloscope sweep was completed, so no data point was available.

## TABLE I

### Experimental Extinguishment Data for Arcite Propellant

| Run | $P_1$(psia) | $P_e$(psia) | $-\frac{dP}{dt}$ $(\frac{psi}{sec})$ | $r_{oe}$ (Theory) | $r_o$ $(\frac{in}{sec})$ (Exper.) |
|---|---|---|---|---|---|
| 1 | 425 | | | | |
| 2 | 430 | 81 | 7.7 | .12 | .16 |
| 3 | 425 | 71 | 6.4 | .12 | .147 |
| 4 | 102 | 25 | 1.55 | .12 | .08 |
| 5 | 99 | 31.7 | 2.88 | .14 | .095 |
| 6 | 105 | 34 | 2.41 | .13 | .098 |
| 7 | 103 | | | | |
| 8 | 223 | 35 | 1.39 | .095 | .10 |
| 9 | 212 | extinguished off record | | | |
| 10 | 214 | | | | |
| 11 | 67.5 | | | | |
| 12 | 71 | 30.6 | 2.08 | .125 | .090 |
| 13 | 76 | 21 | .40 | .066 | .075 |
| 14 | 129 | 40.2 | 3.45 | .14 | .105 |

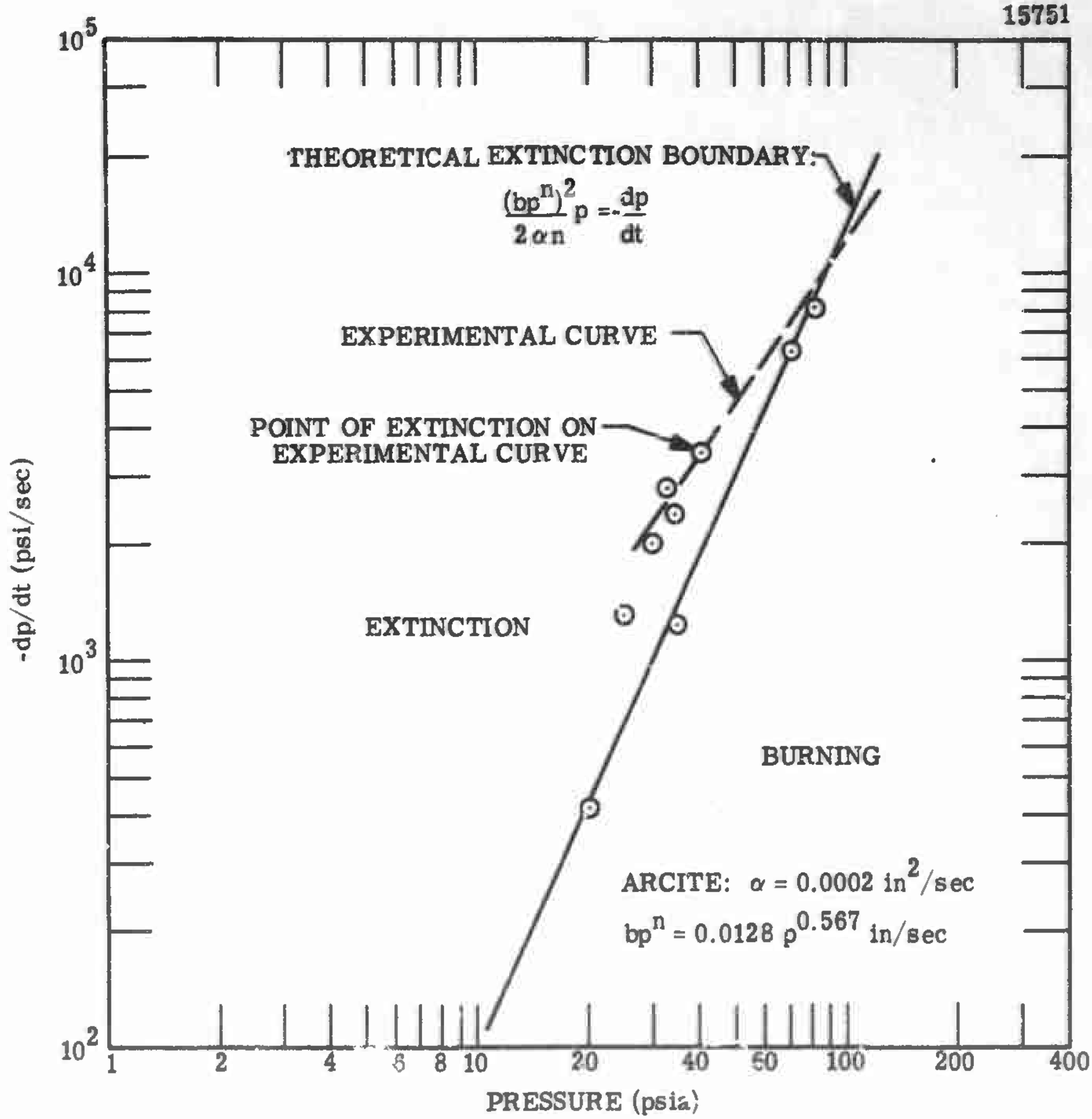



Figure 3. Comparison of Experimental Extinguishment Results for an Arcite Propellant with Theory of Reference 6.

It is apparent that remarkable agreement was obtained between experiment and theory, which we take as mutually supporting evidence for the general validity of both. An equivalent rough check on the approximate correctness of equation (3) can be obtained by computing $r_o$ from

$$r_o = \sqrt{2\alpha n \frac{d \ln P}{dt}} \tag{4}$$

and comparing with the measured $r_o$. These are shown in the last two columns of Table I, and the agreement is very fine.

We have taken Fastax movies of two extinguishment runs at approximately 3000 frames/sec. In one of these we failed to obtain an oscilloscope record although the movie and run otherwise were normal. The second, run #14, was satisfactory and the movie provided a check on whether the phototube was properly monitoring the extinction event. On Figure 2 it can be seen that the luminosity reaches zero at 8.8 milliseconds after the pressure begins to decay. In the movie, the arrival of the expansion wave at the flame front is very apparent and the light intensity was no longer visible 8.7 $\pm$0.2 milliseconds later. This still leaves unsettled a more basic question of whether the combustion process has ceased to be self-sustaining at the instant the visible flame luminosity is no longer detectable.

## IV. REFERENCES

1. Paul, B. E., Lovine, R. L., and Fong, L. Y., "A Ballistic Explanation of the Ignition Pressure Peak," AIAA Preprint 64-121, AIAA 5th Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 1964.

2. Marxman, G. A., "Theoretical Model of Solid Propellant Response in Combustion Instability and Extinction," ICRPG 3rd Combustion Conference, Cocoa Beach, Fla., Oct. 1966 (CPIA Publication No. 138, Vol. I, Feb. 1967), p. 221.

3. Cohen, N. S., "A Theory of Solid Propellant Extinguishment by Pressure Perturbation," ICRPG 2nd Combustion Conference, Los Angeles, Calif., Nov. 1965 (CPIA Publication No. 105, Vol. I, May 1966), p. 677.

4. Horton, M. D., Bruno, P. S., and Graesser, E. C., "Depressurization Induced Extinction of Burning Solid Propellant," ICRPG/AIAA 2nd Solid Propellant Conference, Anaheim, Calif., June 1967, p. 232.

5. Krier, H., T'ien, J.S., Sirignano, W. A., and Summerfield, M., "Non-Steady Burning Phenomena of Solid Propellants: Theory and Experiments," ICRPG/AIAA 2nd Solid Propellant Conference, Anaheim, Calif., June 1967, p. 232.

6. von Elbe, G., "Solid Propellant Ignition and Response of Combustion to Pressure Transients," AIAA Preprint 66-668, AIAA 2nd Propulsion Joint Specialist Conference, Colorado Springs, Colorado, June 1966.

UNCLASSIFIED
Security Classification

**DOCUMENT CONTROL DATA - R&D**

*(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)*

| | |
|---|---|
| 1. ORIGINATING ACTIVITY (Corporate author)<br>Atlantic Research Corporation<br>Alexandria, Virginia | 2a. REPORT SECURITY CLASSIFICATION<br>Unclassified<br>2b. GROUP |

3. REPORT TITLE

RESEARCH ON THE DEFLAGRATION OF HIGH-ENERGY SOLID OXIDIZERS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

QPR - June 1, 1967 to August 31, 1967

5. AUTHOR(S) (Last name, first name, initial)

von Elbe, G. Friedman, R.
McHale, E. T. Levy, J. B.

| | | |
|---|---|---|
| 6. REPORT DATE<br>September 15, 1967 | 7a. TOTAL NO. OF PAGES<br>9 | 7b. NO. OF REFS<br>6 |
| 8a. CONTRACT OR GRANT NO.<br>AF 49(638)-1645<br>b. PROJECT NO.<br>c.<br>d. | 9a. ORIGINATOR'S REPORT NUMBER(S)<br><br>9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) | |

10. AVAILABILITY/LIMITATION NOTICES

| | |
|---|---|
| 11. SUPPLEMENTARY NOTES | 12. SPONSORING MILITARY ACTIVITY<br>Air Force Office of Scientific Research<br>Washington, D. C. |

13. ABSTRACT

A new phase of the program, the study of solid propellant and oxidizer extinguishment by rapid depressurization, began during this quarter. In this report we describe the apparatus used for this work and the results obtained on the first propellant tested.

The apparatus is an optical strand burner modified to allow rapid depressurization by venting. At pressures of 2000 psi, pressure decay rates of 5 x $10^5$ psi/sec can be achieved. Experiments were carried out on a polyvinylchloride-ammonium perchlorate composite propellant, over a range of initial pressures of 68 to 430 psia with decay rates as high as $10^5$ psi/sec. The experimental extinguishment results are compared with theory.

DD FORM 1 JAN 64 1473

UNCLASSIFIED
Security Classification

UNCLASSIFIED

Security Classification

| 14. KEY WORDS | LINK A | | LINK B | | LINK C | |
|---|---|---|---|---|---|---|
| | ROLE | WT | ROLE | WT | ROLE | WT |
| Solid propellant extinguishment<br>Extinguishment of solid propellants | | | | | | |

## INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2a. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8a. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through ________________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through ________________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through ________________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.

UNCLASSIFIED

Security Classification